PB80-213432

Environmental Sources of Trichloroethylene Exposure: Source Contribution Factors

MITRE Corp.
McLean, VA

Prepared for

Environmental Protection Agency
Washington, DC

May 80

U.S. Department of Commerce
National Technical Information Service
NTIS.

United States
Environmental Protection
Agency

Office of
Toxic Substances
Washington, DC 20460

May 1980
EPA-560/11-80-009

Toxic Substances

PB80-213432

EPA

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SPRINGFIELD, VA 22161

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO.	2.	3. RECIPIENT'S ACCESSION NO. PB80 213432
4. TITLE AND SUBTITLE Environemental Sources of Trichloroethylene Exposure Source Contribution Factors		5. REPORT DATE May 1980 6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Myles E. Morse		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS MITRE Corporation Washington Center 1820 Dolley Madison Boulevard McLean, Virginia 22102		10. PROGRAM ELEMENT NO. 11. CONTRACT/GRANT NO. 68-01-5863
12. SPONSORING AGENCY NAME AND ADDRESS Charles L. Trichilo, Ph.D. Assessment Division Office of Pesticides and Toxic Substances U.S. Environmental Protection Agency Washington, D.C. 20460		13. TYPE OF REPORT AND PERIOD COVERED Final 14. SPONSORING AGENCY CODE

15. SUPPLEMENTARY NOTES

16. ABSTRACT

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17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group

18. DISTRIBUTION STATEMENT	19. SECURITY CLASS *(This Report)*	21. NO. OF PAGES
	20. SECURITY CLASS *(This page)*	22. PRICE

EPA Form 2220-1 (9-73)

EPA-560/11-80-009
May 1980

ENVIRONMENTAL SOURCES OF TRICHLOROETHYLENE EXPOSURE:

SOURCE CONTRIBUTION FACTORS

by

M. Morse

The MITRE Corporation, Metrek Division
1820 Dolley Madison Boulevard
McLean, Virginia 22102

Contract No. 68-01-5863

Project Officer

Charles L. Trichilo, Ph.D.
Assessment Division
Office of Pesticides and Toxic Substances
U.S. Environmental Protection Agency
Washington, D.C. 20460

U.S. Environmental Protection Agency
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DISCLAIMER

This report has been reviewed by the Assessment Division, Office of Pesticides and Toxic Substances, U.S. Environmental Protection Agency, and approved for publication. Approval does not signify the contents necessarily reflect the views and policies of the U.S. Environmental Protection Agency, nor does mention of trade names or commercial products constitute endorsement or recommendation for use.

The addition of any referenced data after December 1978 does not indicate that a literature review was conducted after this date.

ACKNOWLEDGMENT

The author wishes to thank Dr. Charles L. Trichilo for his continuous support and encouragement during the preparation of this document.

Appreciation is expressed to the Criteria and Standards Division of the Office of Drinking Water for initiating this work and to Messrs. Roger Garrett and Blake Biles of the Premanufacture Review Division for their support in its completion.

This document was reviewed in final draft form by Dr. James V. Bruckner, Department of Pharmacology and Toxicology, University of Texas, Health Science Center at Houston.

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EXECUTIVE SUMMARY

The MITRE Corporation, Metrek Division has identified and analyzed sources of trichloroethylene in air, food, and drinking water. This report is an assessment of ambient environmental concentrations of trichloroethylene and their percent contribution to man's total daily uptake. It is intended to aid in the identification of those environmental exposures to trichloroethylene posing the greatest health risk.

Total 1978 trichloroethylene production in the United States was 135,903 metric tons. Approximately 80 percent of this was utilized by industry as a degreasing solvent, 9 percent was exported while the remaining 11 percent was used in minor processes (e.g., extraction agent, chemical intermediate), and stored as inventory.

Trichloroethylene is found in all environmental media although, due to its physical characteristics (i.e., high volatility, rapid photodegradability, low solubility in water), it is not considered a persistent contaminant in the atmosphere and surface waters. However, data on trichloroethylene in ground water aquifer systems indicate a greater persistence. There is a constant flow of trichloroethylene into the environment. About 95 percent of that produced in the United States is lost through fugitive emissions and dispersive uses.

Reported ambient concentrations in air are variable, ranging from less than 1 to greater than 100 $\mu g/m^3$. A representative average nonindustrial urban air concentration is 1 $\mu g/m^3$. Maximum air concentrations were noted downwind from chemical landfill sites.

Average dietary intake of trichloroethylene has been estimated to be 10 μg/day. Individual dietary preference can be an important factor in the variation of this value.

A wide range of trichloroethylene concentrations occurs in public water supplies. The values reported vary from less than 1 to greater than 22,000 $\mu g/l$. A value of 0.5 $\mu g/l$ is representative of an average urban concentration. Maximum trichloroethylene concentrations are characteristically found within deep well aquifer systems. Characterization (i.e., industrial, geographical) of trichloroethylene occurrence in drinking water systems is not well defined at this time. Occurrence of trichloroethylene in ground water systems corresponds with residential and industrial use, and subsequent discharge and leaching of products containing trichloroethylene.

Trichloroethylene can be absorbed into the body via pulmonary, gastrointestinal and dermal routes. Pulmonary absorption rates have been reported within a range of 35 to 77 percent, while gastrointestinal absorption rates are assumed to range between 80 and 100 percent of intake. Dermal exposure and absorption are considered negligible.

Absorbed trichloroethylene is metabolized via enzymatic biotransformation. The transformation sequence involves enzymatic oxidation, intramolecular rearrangement and hydrolytic reactions. The major excreted metabolic products are trichloroethanol, trichloroethanol glucuronide, and trichloroacetic acid. Trichloroethanol is of concern due to neurologic effects, while trichloroacetic acid and certain intermediates may be of toxic significance due to protein binding abilities and subsequent hepatorenal cytotoxic effects.

Some accumulation of unmetabolized trichloroethylene has been noted in fatty tissues and is assumed to be a result of its high lipid solubility. Otherwise, a fairly uniform distribution pattern is found within internal organs.

Trichloroethylene, absorbed through the respiratory and gastrointestinal tracts, may be excreted unchanged, or metabolized and excreted as soluble metabolites. The half-life of unmetabolized trichloroethylene ranges from 1 to 20 hours, while the half-life of its metabolites may range from 12 to 58 hours.

Trichloroethylene is eliminated from the body via respired air or the urine, and to a considerably lesser extent in the feces and perspiration. Pulmonary elimination is virtually complete 24 to 48 hours after either pulmonary or gastrointestinal exposure, while urinary excretion of metabolites may persist for 2 weeks.

Based on calculations performed in this document, total trichloroethylene uptake from air, food, and water can range from 26 to 45,492* µg/day in adults and from 9 to 31,111* µg/day in children. The contribution of drinking water to total daily trichloroethylene uptake can range from <1 to 99 percent in both adults and children. This wide range is due to the variability of ambient trichloroethylene concentrations in air and water.

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*It is noted that, at the highest trichloroethylene concentration in water selected for these calculations, the taste of trichloroethylene can be perceived. Therefore, drinking water volume consumed per day would decrease, and a more likely total trichloroethylene daily uptake would be 6992 µg/day in adults and 5811 µg/day in children.

Those subpopulations within the general population that are qualitatively identified as hypersensitive to trichloroethylene are the fetus, children, and those consuming ethyl alcohol. The primary physiological reasons for hypersensitivity to trichloroethylene in each group are the facility of placental permeability, the ease of deposition due to immature organogenesis, and the competitive inhibition or stimulation of the mixed function oxidase enzymes, respectively.

The exposure/uptake approach in this report offers a means of identifying human health risks and in combination with other exposure information can be used in regulatory decision making.

1.0 INTRODUCTION

The Toxic Substances Control Act (TSCA) authorizes the Environmental Protection Agency (EPA) to take various types of actions to identify and mitigate unreasonable risks to health or the environment posed by chemical substances and mixtures. In determining unreasonable risks the agency will perform risk assessments to evaluate the adverse effects on health or the environment that are expected to result from exposure to a chemical.

The MITRE Corporation/Metrek Division has identified and analyzed sources of trichloroethylene uptake from air, food, and drinking water. In this assessment, the contribution from each source to total daily uptake is determined over a broad range of environmental occurrence levels. The source contribution model presented in this study identifies routes of environmental exposure. This model, as well as the identification of sensitive segments of the population, may be used to support regulatory decision making under TSCA.

1.1 Background

Trichloroethylene is widely distributed in the environment, occurring in variable quantities in food, drinking water and the atmosphere. Due to its high rate of atmospheric photodegradation, low water solubility, and high vapor pressure trichloroethylene does not persist in the atmosphere or surface water (Dilling et al. 1976; Moolenar, 1980). It is considered to have greater persistence in ground water than in the atmosphere or surface water (DeWalle, 1979).

However, due to the high volume of trichloroethylene released into the environment (about 80 percent of the production in the United States) there exists a constant influx to the environmental media (EPA, 1977a; Geomet, 1977). Trichloroethylene is thus widely dispersed in food, air and water. Ambient concentrations are usually low, but can show wide variation (Section 3.0).

Trichloroethylene can be absorbed from environmental sources in significant amounts (via pulmonary and gastrointestinal exposure), accumulate in fatty tissues (due to its high lipid solubility), and can cross tissue membranes as well as the placenta (Laham, 1970). Trichloroethylene and its metabolites exert neurologic and hepatorenal toxic effects.* Trichloroethylene has been implicated as a carcinogen (NCI, 1976) in humans. The combination of these factors yields a potential health risk to populations exposed to trichloroethylene.

1.2 Approach

Trichloroethylene is a highly lipid soluble solvent. In order to properly assess the health significance of the ingestion of trichloroethylene-contaminated drinking water, it is necessary to

*It is noted that, although hepatorenal toxicity of metabolized trichloroethylene has been demonstrated, neurotoxicity has not been demonstrated per se, but is alluded to through acknowledgment of acute, reversible CNS depression, and "psychoorganic syndrome" (Ertle et al., 1972). Measurement of neurological dysfunction has not exhibited, to date, the sensitivity necessary to determine the occurrence of residual neurologic effects.

define the contributions to an individual's trichloroethylene uptake from each major source of exposure. These source contribution factors can be defined in three successive steps, i.e.,

- o define and quantify the major environmental sources of trichloroethylene exposure,
- o determine the absorption/metabolism/retention and elimination characteristics of trichloroethylene in man via each exposure route, and
- o estimate total daily uptake of trichloroethylene in man, based on ambient exposures and absorption/retention characteristics.

By examining the percent contribution to the total uptake from each route of exposure, one can calculate the source contribution factors for each type of trichloroethylene exposure. In this way, the significance of trichloroethylene exposure via drinking water can be assessed in view of the other possible exposure routes.

In the process of defining source contribution factors, it often becomes necessary to consider instances where endogenous (e.g., age, physiological condition) or exogenous (e.g., geographical area, occupation) factors can affect the percent contribution from each environmental source. With this in mind, average values for environmental occurrence and absorption are considered as well as maximum reported values, because inclusion of only the average values in calculating the source contribution factors may lead to erroneous conclusions.

This report defines the percent contribution to the total trichloroethylene uptake from all the major environmental sources of

exposure. The report does not, however, consider or evaluate the toxicological implications of such trichloroethylene uptake. Those instances when critical data were insufficient or lacking are pointed out in the text.

2.0 PRODUCTION AND USE

Commercial production of trichloroethylene in the United States began in 1925, yielding only a few hundred tons per year for minor extraction processes. Trichloroethylene was in high demand during the 1930s for use in metal degreasing and dry cleaning (Hardie, 1964).

Production of trichloroethylene has been declining since its peak production of 276,635 metric tons in 1970. Total U.S. production in 1978 was 135,903 metric tons and estimated production in 1979 was 115,739 metric tons (Emanuel, 1980). The decline in production from 1970 is thought to be due to the enforcement of air pollution restrictions (SRI, 1978) since the classification in 1966 of trichloroethylene as a photochemical reactant in smog, and the voluntary discontinuation of trichloroethylene use in food processing after an NCI alert in 1975 of the possible carinogenicity of trichloroethylene in mice (Buxton, 1978).

The two major industrial processes employed to produce trichloroethylene have been (1) oxychlorination of ethylene dichloride and (2) chlorination of acetylene (followed by dehydrochlorination). Prior to 1967, 85 percent of trichloroethylene produced in the United States was derived from acetylene chlorination. Presently, 85 percent of trichloroethylene is produced via the oxychlorination of ethylene dichloride (NIOSH, 1973).

TABLE 2-1

TRICHLOROETHYLENE PRODUCTION* - INDIVIDUAL PLANTS

Company	Location	Annual Capacity (1000 metric tons)
Dow Chemical U.S.A.	Freeport, Texas	68
Ethyl Corporation	Baton Rouge, Louisiana	20
PPG Industries, Inc.	Lake Charles, Louisiana	91
TOTAL		179

Note: The Diamond Shamrock Corporation has a 23 metric ton per year facility which was placed on standby in early 1978.

*Process used by these companies for trichloroethylene production is oxychlorination of ethylene dichloride.

Source: Adapted from SRI, 1979.

There are currently three active producers of trichloroethylene in the United States. Their locations, capacities, and production processes are displayed in Table 2-1.

Trichloroethylene is utilized in a variety of processes in the United States. Over 80 percent is used by industrial metal fabricating plants for vapor degreasing. Other agents such as tetrachloroethylene and methylene chloride have been employed as degreasers since 1960, but trichloroethylene is still used in over 50 percent of this industry (NIOSH, 1973). Of the remaining 20 percent, about 9 percent is exported, less than 10 percent is used as a solvent, chemical intermediate and terminator, while the remainder is stored in inventory (SRI, 1978).

Trichloroethylene had been used until 1976 for the selective extraction of foods,* fish meal, meat meal, oil-containing seeds, soya beans, and coffee beans (decaffination). Current applications include use as a metal cleaning solvent; as a swelling agent in the disperse dyeing of polyesters and in the removal of basting threads by the textile industry; as the raw material for production of a chemical intermediate in fungicide formulation (Difolatan®); and as a chain termination in polyvinyl chloride production (SRI, 1978).

A flowchart of trichloroethylene production and consumption in the United States for 1974 is presented in Figure 2-1.

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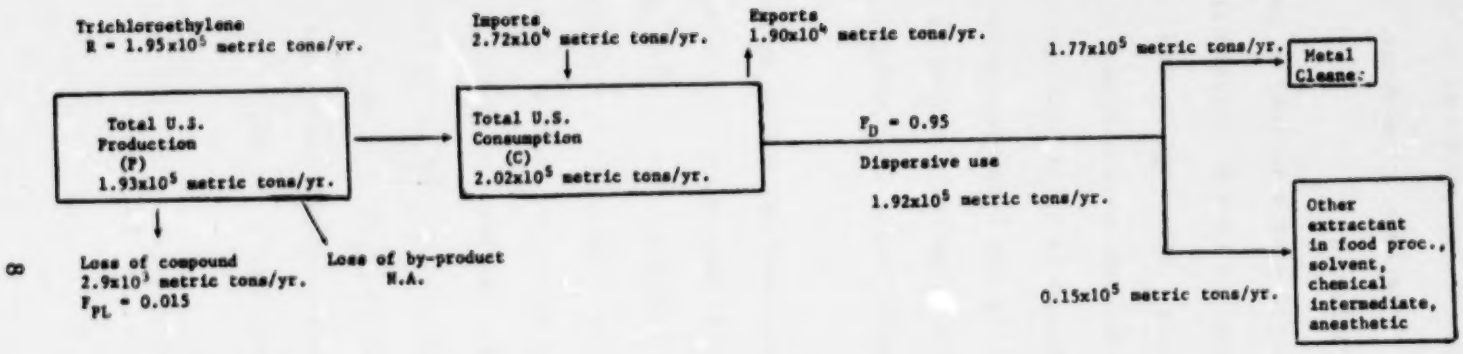
*Actual use of trichloroethylene for extraction purposes in food products was voluntarily discontinued by manufacturers in 1975-76 after an NCI carcinogenicity alert (Buxton, 1978).



Source: Chan et al., 1975.

R = production rate

F_D = fraction dispersal

F_{PL} = fraction of production lost

FIGURE 2-1
SUMMARY OF 1974 PRODUCT RELEASE INFORMATION

3.0 ENVIRONMENTAL SOURCES OF TRICHLOROETHYLENE EXPOSURE

Approximately 95 percent of the total trichloroethylene produced in the United States is lost to the environment each year (EPA, 1977a; Geomet, 1977). The majority of this loss is due to vapor loss and discharge in waste streams from industrial degreasing operations (EPA, 1977a). The great potential for release to the atmosphere during vapor degreasing due to the relatively high volatility of the chemical (i.e., vapor pressure of 57.8 mm Hg at 20°C [Irish, 1967]), has led to objections to the use of trichloroethylene as a solvent in this process (Dale, 1972; Greve, 1971).

Once released to the atmosphere, aerial transport plays a major role in the dissemination of trichloroethylene throughout the environment. The compound transfers rapidly to all compartments of the biosphere. Trichloroethylene is not considered a persistent atmospheric or surface water contaminant (Dilling et al., 1976; Moolenar, 1980). It exhibits low water solubility (i.e., 0.11 g/100g at 20°C) high vapor pressure, and rapid atmospheric photodegradability (Moolenar, 1980; Waters et al., 1977). A transport model for trichloroethylene prepared by Moolenar (1980) shows trichloroethylene leaving the biosphere as rapidly as it is introduced and that it does not accumulate. An estimated half-life of 5 to 12 hours for trichloroethylene (in air) under bright sunlight was reported by Dilling et al. (1976). It is hypothesized, however, that trichloroethylene leaching into deep aquifer systems may be persistent (Fliescher, 1978).

In the sections that follow, trichloroethylene concentrations that have been reported for air,* water,* and food are presented.

3.1 Trichloroethylene Concentrations in Ambient Air

It has been estimated that the average background ambient atmospheric concentration of trichloroethylene is 0.011 $\mu g/m^3$ (Moolenar, 1980). Midwest Research Institute (1977) reported atmospheric levels of trichloroethylene ranging from undetected to 4.94 $\mu g/m^3$ for 27 sites in the United States. Of the sites having trichloroethylene in detectable concentrations, 79 percent had levels greater than 0.05 $\mu g/m^3$. Other monitoring studies have reported trichloroethylene levels greater than 100 $\mu g/m^3$ in industrial areas (Pearson and McConnell, 1975).

Classification of ambient trichloroethylene air concentrations by regional, industrial, or topographical characteristics is somewhat tenuous due to limited monitoring data. It has been proposed that the distribution of trichloroethylene throughout the atmosphere is consistent with its usage (McConnell et al., 1975); however, monitoring data do not consistently support this contention. The lack of supporting monitoring data may be due to the isolated or short-term nature of most trichloroethylene sampling to date. Table 3-1 presents a compilation of reported atmospheric concentrations of trichloroethylene. Analysis of these data indicates increased trichloroethylene air concentrations downwind of landfill sites. Air

*Excludes occupational and/or industrial data.

TABLE 3-1

TRICHLOROETHYLENE CONCENTRATIONS IN AIR

Concentration ($\mu g/m^3$)	Location	Reference	Remarks
Undetected-26.6	United States	Midwest Research Institute, 1977	Ambient air samples from 27 cities or areas in the United States; of the sites for which trichloroethylene was detectable, 79 percent had levels > 0.05 $\mu g/m^3$.
Trace	Edison, NJ	Research Triangle Institute, 1977c.	Sample taken in landfill area.
0.011	---	Moolenar, 1980	Approximate ambient concentration.
0.94	Texas	Research Triangle Institute, 1977c.	Average of nine samples.
~1.0	Torrance, CA	Pellizzari, 1977	
1 - 10	---	McConnell et al., 1975	Typical concentrations.
1.2	Patterson, NJ	Pellizzari, 1977	Only one quantifiable value from eight samples.
1.99 - 27.95	Rural England	Murray and Riley, 1973	
2.69 - 13.97	U.S. excluding La Jolla, CA	Su and Goldberg, 1976	
2.69 - 29.02	La Jolla, CA	Su and Goldberg, 1976	
4.03 - 31.17	Europe	Su and Goldberg, 1976	
5.37 - 107.49	Liverpool/Manchester, England, suburbs	Pearson and McConnell, 1975	
6	Northeast Atlantic and rural Britain	Murray and Riley, 1973	

TABLE 3-1 (CONCLUDED)

Concentration ($\mu g/m^3$)	Location	Reference	Remarks
9.2	Dominquez, CA	Research Triangle Institute, 1977a	
11.0	Edison, NJ	Research Triangle Institute, 1977c	Average concentration, taken upwind from landfill site for chemical waste.
40 - 258	Edison, NJ	Research Triangle Institute, 1977c	Average concentration was 87.5 $\mu g/m^3$. Samples were taken downwind from landfill site.

(Research Triangle Institute, 1977a).

Many values reported in Table 3-1 may not be representative of monthly or annual averages for each site since the duration of most air monitoring has been brief, consisting of single spot checks or 1-day measurements. Daily fluctuations in meteorological conditions can vary ambient air levels erratically. Only long-term sampling programs will provide figures that accurately represent average ambient air concentrations of trichloroethylene.

The household use of trichloroethylene-containing solvents, degreasers, adhesives, etc., in poorly ventilated areas could result in exposure to concentrations far exceeding the environmental levels indicated in Table 3-1. Exposure concentrations from this extremely variable source have been suggested to reach the hundreds to thousands of parts per million range (Bruckner, 1979). There are no data available, however, for further quantification of this exposure source.

3.2 Trichloroethylene Concentrations in the Diet

Quantitative analyses of trichloroethylene content of foodstuffs are extremely limited. Only one study covering a variety of food items in both animal and vegetable categories has been identified in the literature to date. The trichloroethylene concentrations of specific foodstuffs categorized by food class as defined by the Food and Drug Administration (FDA) are presented in Table 3-2.

TABLE 3-2

TRICHLOROETHYLENE CONTENT IN SELECTED FOODSTUFFS

	Food Class[a]	Trichloroethylene Content (μg/kg)[b]
I.	Dairy Products	
	Fresh Milk	0.3
	Cheshire Cheese	3.0
	English Butter	10.0
	Hens' Eggs	0.6
II.	Meat, Fish and Poultry	
	English Beef (Steak)	16
	English Beef (Fat)	12
	Pig's Liver	22
III.	Grain and Cereal Products	
	Fresh Bread	7
IV.	Potatoes	3
V.	Leaf Vegetables	4.6[d]
VI.	Legume Vegetables	4.6[d]
VII.	Root Vegetables	4.6[d]
VIII.	Garden Fruits	
	Tomatoes[c]	1.7
IX.	Fruits	
	Pears	4
	Apples	5
	Black Grapes (Imported)	7
X.	Oils and Fats	
	Margarine	6
	Vegetable Oil	7
	Olive Oil	9
	Cod Liver Oil	19
XI.	Sugar and Adjuncts	
XII.	Beverages	
	Canned Fruit Drink	5
	Light Ale	0.7
	Wine	0.02
	Tea (Packet)	60.0
	Instant Coffee	4.0
	Decaffinated Coffee (packet)	60.0

[a] Food group category according to FDA, 1977

[b] McConnell et al., 1975

[c] Grown on reclaimed lagoon

[d] Averaged values from Groups III, IV, VIII, and IX (McConnell et al., 1975)

Assuming that the concentrations reported by McConnell et al. (1975) are representative of the range and distribution of trichloroethylene in foods and beverages,* it is apparent that an individual's food preferences will vary the total daily intake of trichloroethylene. Estimation of total dietary intake of trichloroethylene involves the utilization of FDA's total diet composition (quantifying food group intake [g/day]) and known concentrations of trichloroethylene in each food group. Table 3-3 displays estimated total trichloroethylene ingested per day by food group. The total dietary intake of trichloroethylene estimated by this method is 13.6 μg/day.

The inclusion of certain beverages can raise the daily trichloroethylene intake. The addition of 1 liter of decaffeinated coffee/tea (assuming 1.6 g of coffee per cup and trichloroethylene concentration @ 60 ppb) to the dietary intake presented in Table 3-3 yields a total dietary trichloroethylene intake of 14.1 μg/day.**

MITRE/Metrek assumes 10 μg/day to be representative of adult dietary trichloroethylene intake. This intake rate is utilized in daily uptake calculations in Section 5.

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*Due to present decreases in production of trichloroethylene, these values may have decreased; however, documented evidence is not presently available to support this.

**Although the FDA is still in the process of officially banning the use of trichloroethylene in the preparation of decaffeinated and instant coffee and tea, the actual use of trichloroethylene in the decaffeination process was terminated by manufacturers in 1975-76 due to an NCI alert (Buxton, 1978) (see Section 5.3). The intent of FDA to delist trichloroethylene from use in the food industry has been announced (Federal Register, 1977).

TABLE 3-3

DAILY ADULT DIETARY[a] INTAKE OF TRICHLOROETHYLENE BY FOOD CLASS

Food Class[b]		Estimated Adult Dietary[c] Trichloroethylene Intake µg/day
I.	Dairy	2.7
II.	Meat, Fish and Poultry	4.5
III.	Grains and Cereals	3.0
IV.	Potatoes	0.5
V.	Leafy Vegetables	0.3
VI.	Legume Vegetables	0.3
VII.	Root Vegetables	0.2
VIII.	Garden Fruits	0.2
IX.	Fruits	1.2
X.	Oils and Fats	0.7
XI.	Sugars and Adjuncts	---
	TOTAL	13.6

[a] Does not include beverages

[b] Food group categories according to FDA, 1977.

[c] Estimated using trichloroethylene concentrations as in McConnell et al., 1975 and FDA diet composition (1977).

3.3 Trichloroethylene Concentrations in Drinking Water

Trichloroethylene is not routinely monitored in surface water. Analyses to date have involved isolated and short-term samples. These random samplings of municipal water supplies, rivers, oceans, and rainwater indicate that the compound is widely distributed at or below the 1 μg/l level (McConnell et al., 1975). However, trichloroethylene concentrations of up to 47 μg/l in finished surface drinking water (EPA, 1977b) have been recorded. The analytical results of these limited samplings are summarized in Table 3-4.

The most extensive monitoring study of trichloroethylene in surface drinking water supplies is that of the National Organics Monitoring Survey (EPA, 1977b). Three phases of this study, each of about 2 months duration, identified measurable concentrations of trichloroethylene in 3, 25, and 18 percent of the 113 community water supplies sampled in each of the three phases, respectively. The mean trichloroethylene concentrations of those samples in which trichloroethylene was identified in each phase were 12, 2.1 and 1.3 μg/l for phases 1, 2, and 3, respectively. The range of detected concentrations found for all three phases was 0.06 to 47.0 μg/l. Mean trichloroethylene values, including those samples in which trichloroethylene was not identified, fell below 1 ug/l for each phase of this study. This appears to be in agreement with the predictions of both McConnell et al. (1975) and Moolenar (1980).

TABLE 3-4

TRICHLOROETHYLENE CONCENTRATIONS IN DRINKING WATER

Concentration (µg/liter)	Location	Reference	Remarks
0.1 - 0.5	10-city survey	EPA, 1975	Found in 5 of 10 drinking waters sampled by the National Organics Reconnaissance Survey (average concentration 0.2 µg/l).
0.0006	--	Moolenar, 1980	Approximation of the background concentration.
0.01 - 1.0	--	McConnell et al., 1975	Typical concentrations expected.
<0.1 - 0.5	5-city survey	Coleman et al., 1975	
Undetected-47	113 municipal water supplies throughout the United States	EPA, 1977b	Average concentration was <1 µg/liter.
<2 - 32	14 cities or areas in the United States	Midwest Research Institute, 1977	Twenty-two cities or areas were sampled.
4* - 300	Nassau County, New York	Myott, 1977	Of 422 samples taken from 377 wells, 54 contained trichloroethylene.
0.01-30.85	Dade County, Florida	Stilwell, 1977	Highest level detected in preliminary sampling data collected from 218 wells. Trichloroethylene detected in 104 wells at an average concentration of 0.62 µg/liter in the quantified samples.
0.2 - 0.5	Huntington, West Virginia	Brass, 1979	Several hundred samples (wells) January 1978 - January 1979 testing period

*Limit of detection

TABLE 3-4 (CONCLUDED)

Concentration (µg/liter)	Location	Reference	Remarks
2200-3500	Collegeville Trappe, Pennsylvania	Blankenship, 1978	Industrial source of contamination (Uniform Tube Co.) As a result, these private wells were destroyed. (30 private and 7 public wells - serving a population of 4500).
22	Smyna, Delaware	Blankenship, 1978	Landfill source of contamination. Use of aeration equipment and boiling water reduced TCE levels to 10 µg/l Public wells serving a population of 12000.
18	Reamstown, Pennsylvania	Blankenship, 1978	Industrial source of contamination - public wells serving a population of 5000.
22000	West Ormrod, Pennsylvania	Blankenship, 1978	Wells destroyed. Source of contamination identified as landfill. 5 public wells serving a population of 650 were contaminated.
20-10000	Danville, Virginia	Blankenship, 1978	Industrial contamination source (Diston, Inc.) Wells were destroyed. 8 wells serving a population of 15000 were contaminated.
4.5	New Castle, Delaware	Blankenship, 1978	Industrial contamintion source. 1 public water supply; 7 wells serving a population of 5500.
5-3100	Bucks County, Pennsylvania	Runowski, 1980	Contamination source unidentified. 11 public water supplies involved; 20 public wells; serving a population of 75,000 (many areas could tap into other water supplies).
undetected - 2500	Montgomery County, Pennsylvania	Runowski, 1980	Industrial contamination. Tube and electronic companies (wells). Mean concentration less than 5 µg/l.
100	Chester County, Pennsylvania	Runowski, 1980	100 wells contaminated by 2 spills. Sources not identified. Over 75% of the private wells in this area were contaminated, serving a population of 650.
0.7 -1420	Long Island, New York	Referente, 1980	Contamination sources unidentified (58 wells).
0.5 - 170	Bergen County, New Jersey	Referente, 1980	Industrial contamination (21 wells).
7 - 600	San Gabriel Valley, Calif.	Love, 1980	Industrial contamination of 17 municipal ground water systems effecting a population of about 3400.

Trichloroethylene is not routinely monitored in ground water supplies. However, due to contamination findings, Pennsylvania now monitors trichloroethylene in ground water on a regular basis (Runowski, 1980). Trichloroethylene concentrations in contaminated ground water are as high as 22000 μg/l while background concentrations are reported at about 0.5 μg/l (Table 3-4).

Extremely high trichloroethylene levels of 3500, 10,000, and 22,000 μg/l were reported in Collegeville Trappe, Pennsylvania, Danville, Virginia, and West Ormrod, Pennsylvania, respectively (mean values were not available). Maximum values reported for Dade County, Florida, and Nassau County, New York, were 30 μg/l and 300 μg/l, respectively, while the mean trichloroethylene concentrations were less than 1 μg/l and less than 10 μg/l, respectively (Table 3-4).

Infiltration of the ground water system has been extensive where trichloroethylene contamination has occurred, effecting a large number of public and private wells. It is apparent that as a result of spill contamination, trichloroethylene can permeate an entire aquifer system. This is exemplified by such areas as Danville, Virginia, Smyrna, Delaware, Collegeville Trappe, Pennsylvania, Reamstown, Pennsylvania, and West Ormrod, Pennsylvania, where in each case the entire community ground water supply was contaminated. As a group, these cases effected a total population of over 40,000 (Runowski, 1980).

Classification of trichloroethylene concentrations in surface water by regional or industrial characteristics is difficult. Ground water supplies appear to have higher levels of trichloroethylene than surface water supplies. Therefore, it may be hypothesized that a population supplied by aquifers has a greater chance of consuming larger amounts of trichloroethylene than one supplied by surface water.

High trichloroethylene levels in ground water correspond with the use and subsequent discharge and leaching of industrial solvents and degreasers (Fliescher, 1978). Occurrences in Pennsylvania, Delaware, Virginia, and California reinforce this point (Table 3-4). However, other high concentration sites (e.g., Nassau County, Bucks County) cannot be classified as industrial areas. Small degreasing operations (e.g., service stations, trucking fleets) were also absent. It is suggested that industrial activity may have contaminated the aquifers as many as ten years prior to the time of measurement and, due to low ambient temperatures, lack of adsorption to sand, and absence of appreciable vaporization the trichloroethylene has remained as a contaminant (Fliescher, 1978). Trichloroethylene is considered a persistent contaminant in deep aquifers with a range in degradation of 1 to 5 years (DeWalle, 1979). In comparison, trichloroethylene in surface water and in the atmosphere is considered to be nonpersistent to moderately persistent, with an estimated degradation range of a few hours to 18 months (Abrahms, 1977; Moolenar, 1980; Smith, 1966).

Another source of trichloroethylene contamination of ground-water supplies in non-industrial areas is the leaching of septic tank cleaning products containing trichloroethylene. It is believed that the use of these cleaners could have created a detectable background concentration of trichloroethylene in ground-water supplies (in addition to any industrial contamination) in areas such as Collegeville Trappe and Bucks County, Pennsylvania (Runowski, 1980).

The EPA and state authorities have dealt with trichloroethylene contamination of ground water supplies by destroying effected wells, or by instituting home treatment of drinking water. Granulated activated carbon filtration units have been shown to reduce trichloroethylene concentrations of 20,000 μg/l to 5 μg/l. The period of effectiveness of the columns is regarded as variable (Runowski, 1980). Boiling water in situations of low level contamination also decreased the contaminant concentrations (Runowski, 1980).

Improper disposal through industrial spills and dumping, public use of septic tank cleaners containing trichloroethylene, improper disposal of other products containing trichloroethylene by the general public, as well as leachate from landfills are identified sources of trichloroethylene contamination of ground-water systems. Implementation of proper disposal practices in each of these cases could obviate hazardous groundwater contamination.

Although there is presently no drinking water standard for trichloroethylene, it has occurred in potable water at sufficient

frequency for the EPA Office of Drinking Water to provide a "suggested no adverse response level" (SNARL) upon request to those needing advice on its health effects as the result of drinking water contamination. A one-day and ten-day SNARL for the child have been provided at 2 mg/liter and 0.2 mg/liter, respectively, for emergency and spill situations with drinking water as the sole or primary source of human intake of trichloroethylene. A long term or chronic SNARL has been provided at 75 μg/l for the child when drinking water is the primary source of explosure and 15 μg/l when additional sources are involved. A drinking water standard or a Maximum Contaminant Level for trichloroethylene is now being developed by the EPA Office of Drinking Water (EPA, 1979).

Based on the available data, MITRE/Metrek has chosen trichloroethylene concentrations of 0.5, 30, 300 and 22,000 μg/l as representative drinking water levels to be used in all uptake calculations presented in Section 5. These values are assumed to be representative of average drinking water concentrations, two high ground water and maximum extreme ground water concentrations, respectively.

4.0 ABSORPTION, METABOLISM, RETENTION, AND ELIMINATION

Trichloroethylene is absorbed in the body after pulmonary, gastrointestinal, and dermal exposure. Approximately one-third of the absorbed trichloroethylene is rapidly eliminated through the pulmonary compartment as unchanged trichloroethylene, while a small amount (less than 10 percent) is eliminated via the urinary tract. The remaining portion of absorbed trichloroethylene is distributed throughout the body, with some accumulation occurring in the fatty tissues, and a majority is metabolized in the liver. This enzymatic process produces trichloroacetic acid, trichloroethanol and trichloroethanol glucuronide as final metabolites which are subsquently eliminated, primarily in the urine. The following sections describe the mechanisms of trichloroethylene absorption, metabolism, retention, and elimination.

4.1 Absorption Characteristics

Kinetic modeling of pulmonary absorption is extensive in the literature since it is a primary route of exposure in occupational settings. Trichloroethylene is absorbed readily through the respiratory epithelium as well as through the gastrointestinal wall. Cutaneous absorption of trichloroethylene is considered negligible from environmental sources. The following sections elucidate the physiological characteristics of each of the three routes of absorption.

4.1.1 Pulmonary Absorption

The pulmonary tract is an entry route for most solvents and vapors. Trichloroethylene vapors are readily absorbed through the respiratory epithelium. Absorption by the pulmonary tract is dependent upon the equilibrium ratio; the rate of pulmonary ventilation; the diffusion through the alveolar capillary and tissue membranes; solubility in blood and tissues; exposure concentrations; the duration of exposure; and the metabolic rate.

The pulmonary absorption rate is greatest upon early exposure, decreasing until an as yet unidentified equilibrium level is reached between inspiratory vapor concentration and trichloroethylene levels in the blood (Astrand and Gamberale, 1978). The percent of pulmonary absorption has been reported to be inversely dependent upon the equilibrium ratio, the quotient of the concentrations in alveolar air and inspiratory air (i.e., the percent uptake decreases as the alveolar concentration increases) (Astrand, 1975; Astrand and Gamberale, 1978). The percent of pulmonary absorption increases with decreasing exposure concentrations (Astrand and Ovrum, 1976).

The quantity of trichloroethylene absorbed by the pulmonary compartment (represented by trichloroethylene concentration in arterial blood) is directly related to alveolar air concentration (Astrand and Ovrum, 1976). However, this relatiorship appears to be limited by the solubility of trichloroethylene in blood (the partition coefficient) (Astrand and Ovrum, 1976).

Total pulmonary absorption has been found to increase during physical exertion due to an overall rise in respiratory and metabolic rate (Astrand and Ovrum, 1976). Although total absorption of trichloroethylene increased during four consecutive exercise periods, the relative absorption in each of the four exercise periods was found to decrease. It is hypothesized that at a higher work output, the rate at which trichloroethylene is supplied to the alveoli is faster than the rate of diffusion from the alveoli to the blood. The low rate of diffusion to the blood is believed to be a result of the low partition coefficient (from alveolar air to blood) of trichloroethylene (Astrand and Ovrum, 1976). An increase in uptake of trichloroethylene is believed to be a result of rapid clearing of trichloroethylene from the blood due to rapid deposition in the tissues (high lipid solubility) and rapid biotransformation by the liver (Astrand and Ovrum, 1976).

A summary of reported absorption percentages for trichloroethylene is presented in Table 4-1. These percentages range from 35 to 77 and are based on exposures ranging from 268 to 2044 mg/m^3. The expected inverse dependency of percent absorption to exposure concentrations is not clearly apparent in Table 4-1. This is probably a result of variation in experimental procedures in addition to individual physiological differences. The distribution of absorption percentages resulting from variable fat content of tissues (Astrand

TABLE 4-1

SUMMARY OF REPORTED PULMONARY ABSORPTION
FOR TRICHLOROETHYLENE IN HUMANS

Percent Absorption	Concentration (mg/m^3)	Duration of Exposure	Reference
75	---	30 minutes	Astrand and Gamberale, 1976
53	540	30 minutes	Astrand, 1975
50	1080	30 minutes	Astrand, 1975
51-64	1043	5 hours	Bartonicek, 1962
55	1355-2044	2.7 hours	Nomiyama and Nomiyama, 1974
50	268	---	Ikeda, 1977
56-60	---	---	Soucek et al., 1952
35-63	1076	7 hours	Stewart et al., 1970
58-70	---	---	Soucek and Vlachova, 1960
74	376	4 hours	Monster et al., 1976
62.5	753	4 hours	Monster et al., 1976
67-77	---	---	Monster et al., 1976

and Ovrum, 1976) may be the result of the small sample size used in these experiments.

Ambient atmospheric trichloroethylene concentrations are significantly less than experimental exposure levels by a factor of 10^5 (Tables 3-1 and 4-1). It is assumed that the percent absorption will be somewhat greater at the lower ambient environmental concentrations than that of the higher experimental concentrations. Therefore, MITRE/Metrek has selected a rate of 65 percent as representative of the reported range of pulmonary absorption. Succeeding chapters will employ the use of this value in source contribution and uptake considerations.

4.1.2 Gastrointestinal Absorption

Analysis of isolated poisoning cases (i.e., attempted suicide) indicate that trichloroethylene passes across the gastrointestinal wall into the blood (Gibitz and Plochl, 1973; Vignoli et al., 1970). There is a paucity of gastrointestinal absorption values in the literature due to limited quantification of blood levels and excreted trichloroethylene in accidental ingestion cases, and a lack of human or animal ingestion studies.

Oral administration of radioactively labeled trichloroethylene to rats resulted in the excretion of 72 to 85 percent of the labeled unchanged trichloroethylene via the pulmonary compartment, while urinary excretion of labeled metabolites represented 11 to 21 percent of the initial exposure. Thus, an estimated 80 to 100 percent of

ingested trichloroethylene was absorbed by the gastrointestinal tract (Daniel, 1963).

Based on Daniel's study, it is assumed that 90 to 100 percent of small amounts of ingested trichloroethylene will be absorbed. Therefore, 100 percent will be utilized as a representative rate of gastrointestinal absorption for all uptake calculations in Section 5.

4.1.3 Dermal Absorption

Trichloroethylene absorbed through the skin travels via the venous blood to the pulmonary compartment where a portion is eliminated according to the blood:alveolar air concentration relationship mentioned in Section 4.1.1. Due to this characteristic distribution cycle, an appreciably large portion of dermally absorbed trichloroethylene is eliminated unchanged through the lungs before reaching other tissues (Sato and Nakajima, 1978). The remaining trichloroethylene is distributed to the body tissues via arterial blood.

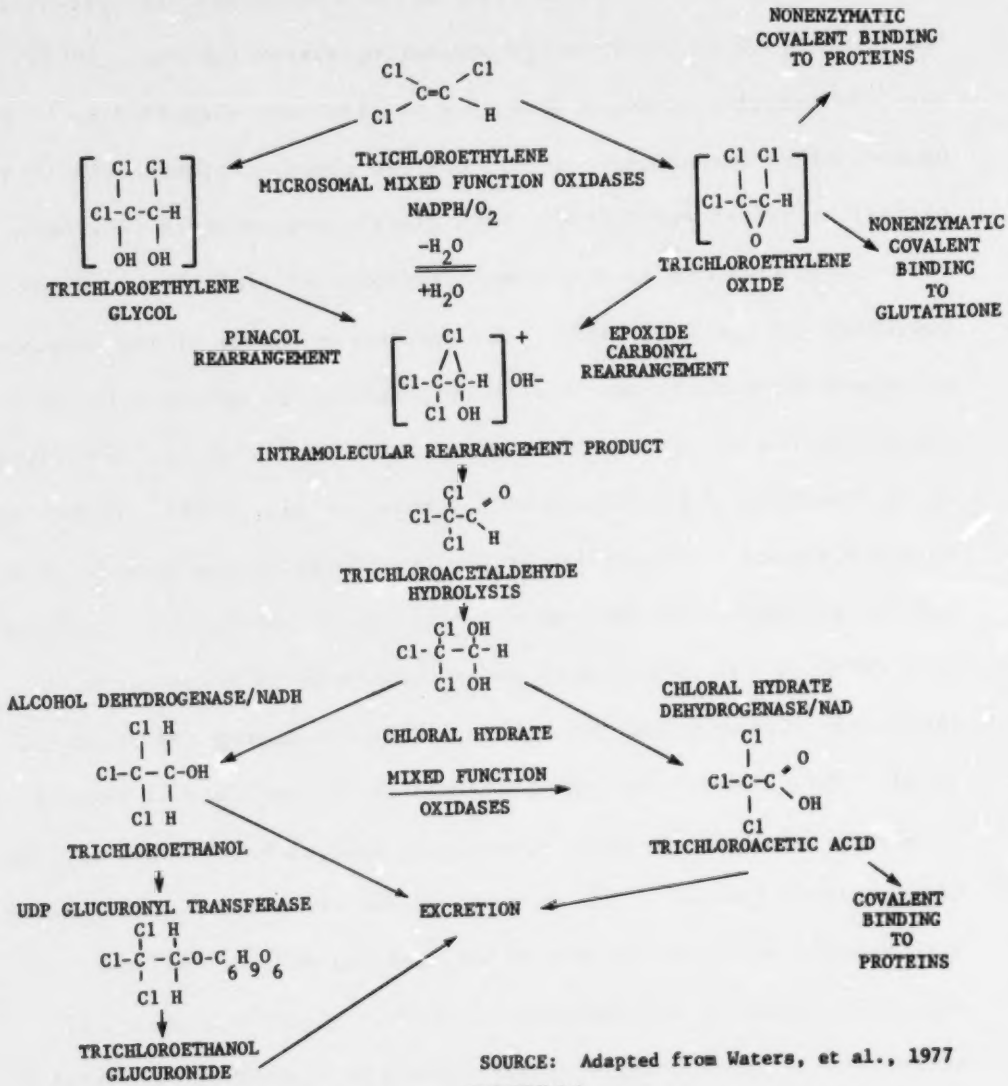
Dermal absorption of trichloroethylene is dependent upon duration of exposure, and extent of surface area exposed. Trichloroethylene absorption through the skin, however, is regarded as negligible under ambient environmental conditions (Malkinson, 1960; Stewart and Dodd, 1964). Since the dermal absorption of toxic quantities of trichloroethylene is considered rare in industrial situations (Sato and Nakajima, 1978), it will not be considered in the calculations that define daily environmental trichloroethylene uptake in Section 5.

4.2 Metabolism: Enzymatic Pathway and Intermediates

The major portion of enzymatic biotransformation of trichloroethylene to its water soluble metabolites occurs within the microsomal fraction of the liver. It has been reported that limited trichloroethylene metabolism occurs within perfused lungs of rats and guinea pigs (Dalbey and Bingham, 1978).

The transformation sequence involves enzymatic oxidation, intramolecular rearrangement, and hydrolytic reactions (Butler, 1949; Leibman, 1965). The hypothesized intermediates and known final metabolites of toxic risk are trichloroethylene oxide and trichloroacetic acid, due to their protein binding tendencies, and trichloroethanol, due to its neurologic effects.

The pathway of trichloroethylene metabolism (Figure 4-1) is fairly well established on the basis of animal data and human blood and urine analyses. The major intermediates and final metabolites have been identified chromatographically and spectrophotometrically, while the unstable, chemically reactive intermediates have been more difficult to identify (Allemand et al., 1978). Although the existence of these unstable intermediates (e.g., chloral hydrate) has been verified in an *in vitro* system (Leibman, 1965), there is no direct evidence for their presence in humans. Therefore, the illustrated pathway presented in Figure 4-1 must be considered hypothetical due to the inclusion of the stepwise formation of these intermediates, their enzymatic catalysts and the final reactive metabolites.



SOURCE: Adapted from Waters, et al., 1977

FIGURE 4-1
PROPOSED METABOLIC PATHWAY FOR TRICHLOROETHYLENE
(ADAPTED FROM WATERS, ET AL., 1977)

The initial step of this metabolic sequence is the oxidation of trichloroethylene. This reaction is catalyzed by the microsomal mixed function oxidase system (considered a hydroxylating system) in the presence of an NADPH-energy generating system (Leibman, 1965). The intermediates produced from this reaction are suggested to be the epoxide (trichloroethylene oxide) and the glycol (trichloroethylene glycol) of trichloroethylene. Both glycols and epoxides have been shown to be products of microsomal oxidation of olefinic compounds (Byington and Leibman, 1965). The particular enzyme of the microsomal mixed function oxidase system responsible for metabolizing trichloroethylene to its epoxide has not been identified but is believed to be cytochrome P-450 dependent (Allemand et al., 1978). Recent research suggests the formation of the trichloroethylene epoxide as the initial intermediate, although not actually isolated, since reactions were enhanced and inhibited by known epoxide hydrase enhancers and inhibitors (Banerjee and Van Duuren, 1978; Van Duuren and Banerjee, 1976). This highly reactive electrophilic intermediate is thought to covalently bind with hepatic proteins as well as hepatic glutathione. Radioactively labeled trichloroethylene has shown metabolite binding with hepatic proteins, nucleic acids, and glutathione (Allemand et al., 1978; Banerjee and Van Duuren, 1978). (Protein binding, if extensive, has been associated with necrotic effects on the liver.)

The reactive epoxide may also easily undergo an epoxide carbonyl rearrangement reaction yielding an unstable chloronium ion intermediate (Byington and Leibman, 1965). This is an intermediate step in the migration of the chlorine atom. Evidence exists supporting a preferred chlorine atom migration within this epoxide rearrangement (McDonald and Schwab, 1963).

The glycol formed in the initial step would be prone to a rearrangement reaction due to the known instability of haloalcohols. The theoretical rearrangement, analogous to the Pinacol rearrangement, would yield the same unstable chloronium ion intermediate produced in the epoxide rearrangement previously described. The common product of these rearrangements indicates the possibility of interconversion of the epoxide and the glycol by hydration and dehydration (Byington and Leibman, 1965). The chloronium ion is unstable, and its association with a hydroxyl ion yields rapid dehydration and continued rearrangement, producing trichloroacetaldehyde as a hypothesized nonvolatile intermediate within the metabolic scheme of trichloroethylene. The existence of chloral hydrate as an intermediate was postulated by Butler in 1949, since the end products of the metabolism of chloral hydrate and trichloroethylene were the same. Chloral hydrate was isolated and identified in rats and dogs by chromatographic, colorimetric and enzymatic techniques in 1965 by Leibman and confirmed by Ikeda and Imamura (1973).

The final stage of this biotransformation is formation of those metabolites that are excreted or accumulated. Chloral hydrate is rapidly metabolized via reduction by liver alcohol dehydrogenase (with an NADH coenzyme) yielding trichloroethanol; and by oxidation via chloral hydrate dehydrogenase (with an NAD coenzyme) producing trichloroacetic acid (Leibman, 1965). It must be further noted that the metabolite trichloroethanol can combine with hepatic glucuronic acid, yielding trichloroethanol glucuronide.

Monochloroacetic acid and chloroform have been implicated as two additional excreted metabolites of trichloroethylene (Soucek and Vlachova, 1960). Their existence as metabolites is still in contention (Monster et al., 1976).

It has been shown that trichloroacetic acid binds with hepatic* and plasma proteins as does trichloroethylene oxide, which can cause displacement reactions with other drugs in the system (e.g., barbiturates), as well as initiate cytotoxic effects (Banerjee and Van Duuren, 1978; Bolt and Filser, 1977; Ertle et al., 1972; Muller et al., 1972; Muller et al., 1975; Soucek and Vlachova, 1960). The final excreted metabolites of this biotransformation pathway are trichloroacetic acid, trichloroethanol, and trichloroethanol glucuronide.

*In vitro experimentation.

4.3 Retention Characteristics

Immediately after absorption, trichloroethylene is carried in the blood to the body organs and tissues. Powell (1947) concluded that trichloroethylene was carried by the hemoglobin in the erythrocytes. Analysis of trichloroethylene distribution in rats revealed 41 percent of the total absorbed to be carried in the blood cellular components and 2.5 percent within the plasma (the remaining portion of absorbed trichloroethylene was expired) (Fabre and Truhaut, 1952). It is hypothesized that trichloroethylene is absorbed and transported by the lipids within the erythrocyte membrane (Fabre and Truhaut, 1952). Although this hypothesis has been disputed by other investigators, the precise nature of trichloroethylene transport has not yet been determined (Bruckner, 1979). Trichloroethylene is rapidly cleared from the blood via deposition, metabolic biotransformation and excretion.

The high lipid solubility of trichloroethylene results in deposition and accumulation of the compound within tissues according to their lipid content. Human autopsy studies revealed the presence of trichloroethylene in most organs, with highest concentrations occurring within the body fat and liver (McConnell et al., 1975).

Distribution of trichloroethylene and its metabolites in animal tissues was shown to be dependent upon the duration of exposure. Concentrations of trichloroethylene were reported after chronic exposure in the body fat, adrenals, and ovaries while the spleen

showed higher concentrations of trichloroacetic acid (Waters et al., 1977). The lungs were found to retain the highest concentration of trichloroacetic acid after chronic exposures, while the gonads and the spleen retained the highest amounts after acute exposures (Smith, 1966).

The length of time that trichloroethylene is retained in the fatty tissue has not yet been determined; however, the biological half-life of the majority of trichloroethylene which is destined to be metabolized has been determined to be 13 to 41 hours (Ikeda and Imamura, 1973; Muller et al., 1975). (This range was determined by occupational exposures to vapor for durations of 4 hours twice a month [10 to 150 ppm] to daily intermittent exposures up to 200 ppm 8 hours/day 5 days a week.) The half-life of that portion of trichloroethylene that is eliminated by the pulmonary compartment ranges from 1 to 20 hours (Stewart et al., 1970); Ikeda (1977) calculated this respiratory half-life to be 25 hours. The biological half-life for the two major metabolites as determined through urinary analysis ranges from 36.1 to 57.6 hours for trichloroacetic acid and from 12 to 49.7 hours for trichloroethanol (Bartonicek, 1962; Ertle et al., 1972; Ikeda and Imamura, 1973; Nomiyama and Nomiyama, 1971; Stewart et al., 1970). The longer half-life (or slower excretion rate) of trichloroacetic acid is caused by its binding to plasma proteins (Muller, 1975). The extent of binding was found to be approximately 90 percent (where trichloroacetic acid concentrations ranged from 10

to 50 μg/ml) (Muller et al., 1975). The shorter half-life of trichloroethanol is due to the ease of excretion of trichloroethanol and its glucuronide (Muller et al., 1975). Due to the varied retention rates of the trichloroethylene metabolites, their 24-hour urinary excretion is not a representative indicator of prior trichloroethylene exposure (especially in an environment of fluctuating exposure) (Muller et al., 1972).

4.4 Elimination Characteristics

Trichloroethylene and its metabolites are eliminated from the body via respired air and urine and, to a considerably lesser extent, through the feces and perspiration. The elimination kinetics of trichloroethylene and its metabolites show varied excretion rates as revealed by comparison of their half-lives (Section 4.3).

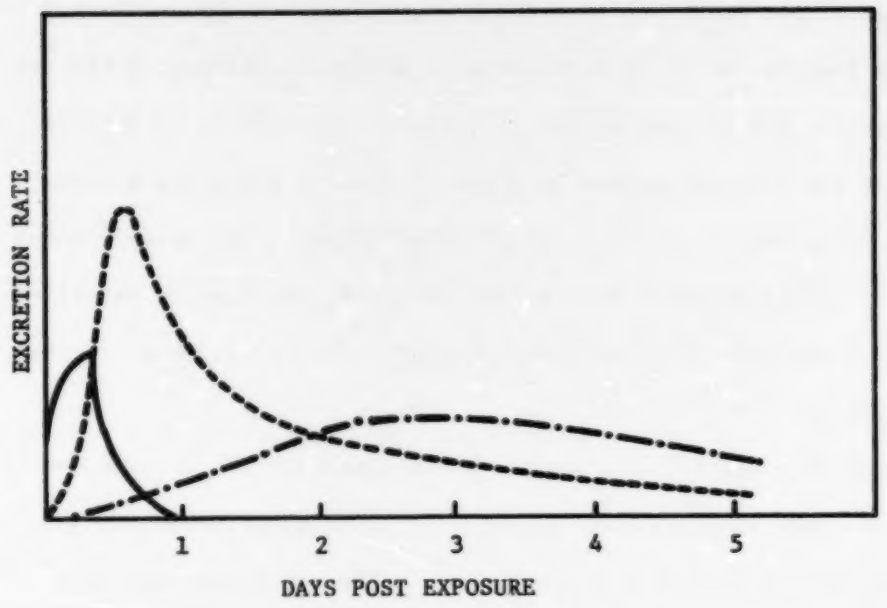
Respired air appears to be the major route of elimination for unmetabolized trichloroethylene, with elimination beginning immediately after exposure. Trichloroethylene concentration decreases rapidly in expired air, with detectable levels remaining as long as 88 hours after 7 hours exposure to 200 ppm (Stewart et al., 1970). Trichloroethanol is excreted via the lungs in man for about four days after exposure (Bartonicek, 1962). Elimination via this route becomes negligible 24 to 28 hours after exposure (Ahlmark and Forssman, 1951; Powell, 1947). In one study, the highest concentrations of trichloroethylene in expired air were noted after three hours of exposure to 200 ppm atmospheric trichloroethylene (Stewart et al.,

1970). An average of 10 percent (range of 7 to 17) of absorbed trichloroethylene was eliminated via respiratory air after inhalation exposures of 4 hours duration to 70 and 140 ppm trichloroethylene (Monster et al., 1976).

The urinary tract is responsible for the elimination of the major portion of trichloroethylene metabolites. Urinary excretion of unmetabolized trichloroethylene is very slight (Fabre and Truhaut, 1952; Powell, 1947). Urinary excretion of trichloroethylene metabolites has been reported to account for 65 to 75 percent of the trichloroethylene retained in the body after respiratory exposure (Ogata et al., 1971; Soucek and Vlachova, 1960). Urinary excretion accounted for 11 to 21 percent of an oral dose in rats (Daniel, 1963).* The concentration of metabolites in human urine range in composition from 38 to 53.1 percent trichloroethanol and from 18.1 to 35.7 percent trichloroacetic acid (Bartonicek, 1962; Ogata et al., 1971; Soucek and Vlachova, 1960).

The urinary excretion kinetics of trichloroethylene metabolites appear to be biphasic (Figure 4-2). It has been documented that the

*It is noted that very high doses of trichloroethylene were administered to these rats (1.8 to 3.9 g). The proportion of the dose that is metabolized is expected to vary inversely with the magnitude of the dose. Therefore, it is presumed that, if relatively small amounts of trichloroethylene were given, a majority of the dose would be metabolized and a greater percentage of metabolic products would be excreted in the urine (Bruckner, 1979; Daniel, 1963).



SOURCE: Adapted from Piotrowski, 1977

FIGURE 4-2
EXCRETION KINETICS OF TRICHLOROETHYLENE AND ITS METABOLITES IN HUMANS

trichloroethanol/trichloroacetic acid elimination ratio increases rapidly immediately after exposure (due to the shorter half-life of trichloroethanol) while 24 to 48 hours after exposure the ratio is reversed. The excretion of trichloroacetic acid in humans lasted nearly 2 weeks (while trichloroethanol excretion was negligible for the latter part of this period) (Muller et al., 1972). Trichloroethanol was found to appear as a glucuronide in the urine within 2 hours of pulmonary exposure, reaching a maximum level roughly twice that of trichloroacetic acid within 24 hours, after which excretion declined exponentially, showing negligible levels for about 2 weeks (Bartonicek, 1962).*

Monochloroacetic acid was found to appear in the urine a few minutes after initiation of exposure to trichloroethylene with maximal levels appearing after 5 hours. The estimated half-life was 15 hours, with negligible levels found after 4 days (Soucek and Vlachova, 1960). About 4 percent of absorbed trichloroethylene was assumed to be excreted in this form.

Other elimination routes releasing lesser amounts of trichloroethylene metabolites are those of fecal excretion and perspiration. Fecal elimination of 8.4 percent of metabolized trichloroethylene (in the form of trichloroethanol and trichloracetic acid) has been

*Figure 4-2 shows a decline of metabolite excretion to a negligible level, but has only been extrapolated for 5 days.

reported in humans (Bartonicek, 1962). Perspiration concentrations were recorded as 0.1 to 1.9 mg/100 ml trichloroethanol and 0.15 to 0.35 mg/100 ml trichloroacetic acid, and were assumed to be negligible (Bartonicek, 1962).

5.0 SOURCE CONTRIBUTIONS TO DAILY TRICHLOROETHYLENE UPTAKE IN HUMANS

Due to the multimedia exposure to trichloroethylene, it is necessary to employ a source contribution model to identify daily exposure/uptake relationships. The utilization of ambient environmental levels in the source contribution model will ascertain the total daily intake of trichloroethylene for an individual and determine the relative magnitude of trichloroethylene contribution from drinking water.

5.1 Approach

The method employed in this study to estimate the degree to which each major environmental source of trichloroethylene exposure contributes to an individual's total daily uptake is based on probable exposure conditions (i.e., ambient trichloroethylene levels) as well as absorption rates for each exposure route. The method consists of a five-step process:

- Definition of ambient concentrations of trichloroethylene for the major exposure sources (i.e., air, food, and drinking water).

- Determination of daily trichloroethylene intake according to the relationship:

$$I_i = C_i \cdot [TRI]_i$$

  where I_i is the daily trichloroethylene intake from source i (i.e., air, food, drinking water), C_i is the consumption per day of each trichloroethylene source i and $[TRI]_i$ is the concentration of trichloroethylene in each source i.

- Calculation of the amount of trichloroethylene absorbed from each exposure source i:

$$U_i = I_i \cdot A_i$$

where U_i is trichloroethylene uptake for each exposure source i, I_i is daily trichloroethylene intake from each source i, and A_i is the percent absorption of trichloroethylene, via the appropriate exposure route, for a particular source.

- Calculation of the total trichloroethylene uptake from all sources (U_t):

$$U_t = \Sigma(I_i \cdot A_i) = \Sigma U_i$$

- Determination of the proportion (P_i) of total daily uptake (U_t) provided by each of the three exposure sources (i.e., source contribution factors):

$$P_i = \frac{U_i}{U_t} \cdot 100$$

5.2 Basic Assumptions

Several assumptions were made in defining the amount of each source material consumed each day. When possible, Reference Man* values were utilized for daily air and food consumption rates (see Table 5-1). Daily consumption of drinking water is that value suggested by NAS (1977) and Snyder et al. (1975), i.e., 2.0 l/day for adults and 1.4 l/day for children.

Pulmonary and gastrointestinal absorption percentages utilized in the calculations are also specified in Table 5-1. These figures represent absorption values for inhaled or ingested trichloroethylene, as reported in the scientific literature. Pulmonary and gastrointestinal absorption rates are assumed to be the same in the

*From the ICRP Reference Man Tables (Snyder et al., 1975).

TABLE 5-1

BASIC ASSUMPTIONS EMPLOYED IN THE
CALCULATION OF INDIVIDUAL SOURCE CONTRIBUTION FACTORS

Basic Assumptions		Remarks
• Reference Man:		
Adult consumes:	2.0ℓ H_2O/day	- Daily intake as suggested by NAS (1977).
	∿2200g food/day	- Approximate daily intake for 18 yr old in FDA total diet studies; comparable to Reference Man (Snyder et al., 1975); however, since daily trichloroethylene intake from the total diet will be assumed, this figure is not used in the calculations.
	22.8 m^3 air/day	- Assumes 8 hrs light work, 8 hrs nonoccupational, and 8 hrs resting.
Child consumes:	1.4ℓ H_2O/day	- Conservative estimate; <2 yr old child assumed to obtain liquid from foods alone.
	∿1000g food/day	- Approximate daily intake for child.
	4.7 m^3 air/day	- For 1 yr old; 0.8 m^3/day for newborn.
• Absorption Characteristics:		
Gastrointestinal		
Adult	100%	- Approximation based on limited data (see Section 4.1.2).
Pulmonary		
Adult	65%	- Representative mid-range value in reported literature (see Section 4.1.1).
Dermal	Insignificant	- Relatively unimportant, except in rare circumstances.

child as in the adult, since there are no empirical data to suggest otherwise.

5.3 Estimated Daily Trichloroethylene Uptake From All Sources

The relative contribution to an individual's daily trichloroethylene uptake from each of the three exposure routes was determined by using average environmental trichloroethylene occurrence data in the calculation sequence previously described. Several concentrations of trichloroethylene in air and drinking water and one value for daily intake from food are utilized to represent the range of values reported. Table 5-2 provides the exposure values used in the calculations.

It should be noted that the assumed total daily dietary intake of trichloroethylene reflects the inclusion of coffee and tea in the diet. The maximum intake per day for a coffee/tea drinker would be an additional 0.5 μg trichloroethylene (assuming 1 liter of coffee/tea per day). This addition proves to be negligible with respect to percent contribution. Although the FDA is in the process of officially banning the use of trichloroethylene in the preparation of decaffeinated and instant coffee and tea, the actual use of trichloroethylene in the decaffeination process was terminated by manufacturers in 1975-1976 due to an NCI alert (Buxton, 1978).

Table 5-3 provides an example of the actual calculation sequence employed. The source contribution factors for air, food and drinking water for adults are summarized in Table 5-4, and for children in Table 5-5.

TABLE 5-2

REPRESENTATIVE ENVIRONMENTAL TRICHLOROETHYLENE EXPOSURE LEVELS

Exposure Routes	Exposure Level	Remarks
Diet		
Adult	10 µg/day	Estimated mean dietary intake (see Table 3-3).
Child (2 yr old)	5 µg/day	Estimated mean dietary intake (see Table 3-3) (assuming 0.45 adult value) (Snyder et al., 1975).
Ambient Air	1 $\mu g/m^3$	Representative mean urban value (see Table 3-1).
	10 $\mu g/m^3$	Representative high urban value (see Table 3-1).
	100 $\mu g/m^3$	Representative maximum value (see Table 3-1).
Drinking Water	0.5 µg/ℓ	Representative mean urban value (see Table 3-4).
	30 µg/ℓ	Representative high value (well sample) Table 3-4).
	300 µg/ℓ	Representative high value (well sample) (see Table 3-4).
	22000 µg/ℓ	Maximum extreme value (well sample) (see Table 3-4).

TABLE 5-3

CALCULATION SEQUENCE IN DETERMINING SOURCE CONTRIBUTION FACTORS

Source	Ambient Concentrations	x	Consumption Rate	x	Absorption Rate	=	Daily Uptake	Percent of Total Uptake
Drinking Water	0.5 µg/ℓ		2ℓ		1.0		1 µg/day	4
Food	10 µg/day		--		1.0		10 µg/day	38
Air	1 µg/m^3		22.8 m^3/day		0.65		15 µg/day	58
					TOTAL		26 µg/day	100

TABLE 5-4

ESTIMATED DAILY TRICHLOROETHYLENE UPTAKE (ADULTS)

	Air @ 1 µg/m³				Air @ 10 µg/m³				Air @ 100 µg/m³			
	Source	Level	Uptake (µg/day)	Percent Contribution	Source	Level	Uptake (µg/day)	Percent Contribution	Source	Level	Uptake (µg/day)	Percent Contribution
Water @ 0.5 µg/l	Air	1 µg/m³	15	58	Air	10 µg/m³	148	93	Air	100 µg/m³	1482	99
	Food	10 µg/day	10	38	Food	10 µg/day	10	6	Food	10 µg/day	10	<1
	Drinking Water	0.5 µg/l	1	4	Drinking Water	0.5 µg/l	1	<1	Drinking Water	0.5 µg/l	1	<1
	Total		26		Total		159		Total		1493	
Water @ 30 µg/l	Air	1 µg/m³	15	18	Air	10 µg/m³	148	68	Air	100 µg/m³	1482	96
	Food	10 µg/day	10	12	Food	10 µg/day	10	5	Food	10 µg/day	10	<1
	Drinking Water	30 µg/l	60	70	Drinking Water	30 µg/l	60	27	Drinking Water	30 µg/l	60	4
	Total		85		Total		218		Total		1552	
Water @ 300 µg/l	Air	1 µg/m³	15	2	Air	10 µg/m³	148	20	Air	100 µg/m³	1482	71
	Food	10 µg/day	10	2	Food	10 µg/day	10	1	Food	10 µg/day	10	<1
	Drinking Water	300 µg/l	600	96	Drinking Water	300 µg/l	600	79	Drinking Water	300 µg/l	600	29
	Total		625		Total		758		Total		2092	
Water @ 22000 µg/l	Air	1 µg/m³	15	<1	Air	10 µg/m³	148	<1	Air	100 µg/m³	1482	3
	Food	10 µg/day	10	<1	Food	10 µg/day	10	<1	Food	10 µg/day	10	<1
	Drinking Water	22000µg/day	44000*	99	Drinking Water	22000µg/day	44000	99	Drinking Water	22000 µg/day	44000*	97
	Total		44025		Total		44153		Total		45492	

* It is noted that the taste of trichloroethylene can be perceived at concentrations above 500 µg/l, therefore in this case, it is more probable that approximately one cup (½ liter) rather than 2 liters would be ingested. In this case uptake from water would be 5500 µg/l and the total daily uptake of trichloroethylene would be 5525; 5658; and 6992 µg/day at air concentrations of 1; 10; and 100 µg/m³, respectively.

TABLE 5-5

ESTIMATED DAILY TRICHLOROETHYLENE UPTAKE (CHILD)

	Air @ 1 µg/m³				Air @ 10 µg/m³				Air @ 100 µg/m³			
	Source	Level	Uptake (µg/day)	Percent Contribution	Source	Level	Uptake (µg/day)	Percent Contribution	Source	Level	Uptake (µg/day)	Percent Contribution
Water @ 0.5 µg/l	Air	1 µg/m³	3	33	Air	10 µg/m³	31	84	Air	100 µg/m³	306	98
	Food	5 µg/day	5	56	Food	5 µg/day	5	13	Food	5.0 µg/day	5	2
	Drinking Water	0.5 µg/l	1	11	Drinking Water	0.5 µg/l	1	3	Drinking Water	0.5 µg/l	1	<1
	Total		9		Total		37		Total		312	
Water @ 30 µg/l	Air	1 µg/m³	3	6	Air	10 µg/m³	31	40	Air	100 µg/m³	306	87
	Food	5 µg/day	5	10	Food	5 µg/day	5	6	Food	5.0 µg/day	5	1
	Drinking Water	30 µg/l	42	84	Drinking Water	30 µg/l	42	54	Drinking Water	30 µg/l	42	12
	Total		50		Total		78		Total		353	
Water @ 300 µg/l	Air	1 µg/m³	3	<1	Air	10 µg/m³	31	7	Air	100 µg/m³	306	42
	Food	5 µg/day	5	1	Food	5 µg/day	5	1	Food	5.0 µg/day	5	<1
	Drinking Water	300 µg/l	420	98	Drinking Water	300 µg/l	420	92	Drinking Water	300 µg/l	420	58
	Total		428		Total		456		Total		731	
Water @ 22000 µg/l	Air	1 µg/m³	3	<1	Air	10 µg/m³	31	<1	Air	100 µg/m³	306	<1
	Food	5 µg/day	5	<1	Food	5 µg/day	5	<1	Food	5.0 µg/day	5	<1
	Drinking Water	22000 µg/l	30800*	99	Drinking Water	22000 µg/l	30800*	99	Drinking Water	22000 µg/l	30800*	99
	Total		30808		Total		30836		Total		31111	

* It is noted that the taste of trichloroethylene can be perceived at concentrations above 500 µg/l, therefore in this case, it is more probable that approximately one cup (¼ liter) rather than 1.4 liters would be ingested. In this case uptake from water would be 5500 µg/l and the total daily uptake of trichloroethylene would be 5508; 5536; and 5811 µg/day at air concentrations of 1; 10; and 100 µg/m³ respectively.

The relative contribution of trichloroethylene in drinking water to the estimated total daily uptake is variable, due to the extremely broad range in ambient water and air concentrations (Tables 3-1 and 3-4). The percent contribution of trichloroethylene in drinking water to total daily uptake in both children and adults ranges from <1 to 99 depending on the ambient water and air exposure levels (Table 5-4 and 5-5).

The predominant source of trichloroethylene uptake alternates between water and air, depending on the ambient concentrations considered; however, given the most frequently occurring ambient concentrations, the atmosphere is the source of greater significance. At these average ambient levels of trichloroethylene (1 $\mu g/m^3$ in air and 0.5 $\mu g/l$ in drinking water), air contributes 58 percent to the daily uptake, while drinking water contributes only 4 percent in adults (Table 5-4).

Water is the predominant source of trichloroethylene absorption in children in situations characterized by drinking water levels of 30 $\mu g/l$ with concurrent air concentrations of 1 and 10 $\mu g/m^3$; and in all situations where drinking water trichloroethylene levels are 300 or 22,000 $\mu g/l$. Assuming the trichloroethylene concentration in air is 1 $\mu g/m^3$ (estimated urban average), drinking water contributes 84, 98 and 99 percent of the total daily trichloroethylene uptake at 30, 300 and 22,000 $\mu g/l$, respectively.

Quantitative characterization of the uptake situations shown in Tables 5-4 and 5-5 is tentative due to limited monitoring data in air, food, and surface water. From the representative concentrations selected ambient levels for air and drinking water of 1 $\mu g/m^3$ and 0.5 $\mu g/l$, respectively, appear to occur most frequently and affect the largest portion of the general population.

Trichloroethylene concentrations in drinking water ranging from 30 to 22,000 $\mu g/l$ contribute significantly to the total daily uptake. These levels have been found only in ground water aquifers (Table 3-4). The source of many of these high trichloroethylene concentrations is considered to be a result of improper disposal of trichloroethylene and products containing trichloroethylene by both industrial and residential users.

If trichloroethylene air levels are presumed to be dependent upon extent of industrial use, populations adjacent to industrialized and landfill areas have the potential for increased uptake and corresponding risk. The worst case situations presented in Tables 5-4 and 5-5 (i.e., air levels of 100 $\mu g/m^3$ and drinking water levels of 300 or 22,000 $\mu g/l$) would be characteristic of an area downwind from a landfill or industry and supplied with drinking water from a contaminated aquifer. It is not clear that this situation actually exists. If it does, it would be expected to affect a limited portion of the general population.

Approximately 50 percent of the U.S. general population relies on ground-water systems as a source of drinking water (Morton, 1976). Since ground-water contamination has been identified with increasing frequency, a larger portion of the general population will be exposed to trichloroethylene.

Analysis of exposure levels of trichloroethylene for the child (Table 5-5) reveals that the 1 day SNARL value is exceeded in all scenarios where the trichloroethylene concentration in water is 22,000 μg/l.* The 10-day SNARL value is exceeded in all scenarios where a drinking water concentration of 300 μg/l occurs. As previously indicated, these concentrations would apply to only a limited portion of the population. However, it is noted that a larger portion of the population exceeds the chronic SNARL value of 75 μg/l. In addition, the SNARL value drops to a concentration of 15 μg/l when sources other than drinking water are prevalent. In this case a larger portion of the population would be exposed to trichloroethylene concentrations in drinking water exceeding the chronic SNARL value (this would include all scenarios above the average drinking water concentration in Table 5-5).

It has been estimated that the taste threshold value for trichloroethylene in water is 500 μg/l (Blankenship, 1980). Therefore populations ingesting trichloroethylene in drinking water above the

*It is noted that the 1- and 10-day SNARL values have been exceeded in numerous instances in Table 3-3.

chronic SNARL values (15 g/l and 75 g/l) as well as those ingesting water above the 10-day SNARL value, would not be aware of the presence of trichloroethylene in the water.

Due to the increased number of children in the general population that could be affected by trichloroethylene concentrations of 15 g/l or greater in drinking water, regulatory action which would aid in the limitation of trichloroethylene exposure should be considered.

5.4 Identification of Critical Receptors

In order to thoroughly elucidate the toxicological significance of environmental trichloroethylene it is important to identify those specific subunits of the population (subpopulations) that are inherently more susceptible to the deleterious affects of the compound. Due to a lack of laboratory, case, and epidemiological studies, extrapolation of general physiological knowledge is utilized to identify these susceptible populations.

Three subpopulations within the general population (i.e., the fetus; the infant or young child; and those under the influence of ethyl alcohol) exhibit the capacity for enhanced sensitivity to trichloroethylene. The use of trichloroethylene as an obstetrical anesthetic has provided an excellent opportunity to determine whether placental transfer took place. In one study, analysis of maternal and fetal blood revealed that unmetabolized trichloroethylene easily diffused through the placenta (Laham, 1970). The lack of development of many enzyme systems, and the deficiency of a blood-brain barrier

in the fetus readily promote accumulation of trichloroethylene and its metabolites after placental transfer. Any accumulation could be extremely dangerous to the fetus due to the suggested neurotoxic effects of trichloroethylene metabolites and their ability to bind and precipitate proteins. The lack of a blood-brain barrier renders the fetal central nervous system particularly sensitive to any damaging effects that may be characteristic of trichloroethylene metabolites (Casarett and Doull, 1975), while the immature state of organogenesis in the fetus provides additional easily damaged targets for these chemicals.

In a study of ten pregnant women exposed (via inhalation) to trichloroethylene as an obstetrical anesthetic, Laham (1970) found that the ratios of trichloroethylene concentration in fetal to maternal blood ranged from 0.52 to 1.9 with a mean of about 1. Placental transfer of trichloroethylene appears to function in a 1:1 relationship. The fetus is, therefore, vulnerable to approximately those same concentrations absorbed by the pregnant female under various exposure conditions.

For reasons of immature physiologic development paralleling those for the fetus, the newborn infant and the young child can also be identified as critical receptors within the population. Neurological development proceeds at a rapid pace from the third trimester of pregnancy until several years postpartum, and permanent neurological damage may result if an individual is stressed (i.e., ingestion

of toxic substances, starvation inducing nutritional deficiencies) during this sensitive period of growth (NAS, 1976). It is assumed that the neurotoxic and hepatorenal toxic effects of trichloroethylene would be amplified due to the child's inherent sensitivity during the growth spurt. Slower or partial metabolic breakdown (due to limited development of enzymatic systems) may lead to enhanced deposition of trichloroethylene within the central nervous system.

Human sensitivity to trichloroethylene is increased after consumption of even small amounts of ethyl alcohol and concurrent or subsequent exposure to trichloroethylene. Ethyl alcohol is thought to interact with trichloroethylene through competitive inhibition of the mixed function oxidase enzymes required for the metabolism of both chemicals. This competitive inhibition yields increased trichloroethylene and ethanol levels in the blood due to the lower rate of metabolism (Muller et al., 1975). The build-up of trichloroethylene in the blood, along with its characteristic high lipid solubility, is believed to lead to its deposition and accumulation within the central nervous system. Concentrations are believed to approach subhypnotic levels, yielding early onset of intoxication symptoms (Muller et al., 1975). Pre-exposure to ethanol, a microsomal enzyme-inducing agent, can result in enhanced metabolism of trichloroethylene to its cytotoxic metabolites, thereby potentiating hepatorenal toxicity (Priest and Horn, 1965). Similar accentuation of trichloroethylene hepatotoxicity is noted after the ingestion of barbiturates

(microsomal enzyme-inducing agents) (Moslen et al., 1977). Due to data limitations, it is not possible to estimate the effect this condition might have on the factors utilized in the source contribution model, and it is also not possible to quantify the size of this population.

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